

APPENDIX F
RISK CHARACTERIZATION EQUATIONS AND VARIABLE VALUES
(23 Pages)

APPENDIX F

RISK CHARACTERIZATION EQUATIONS

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LIST OF VARIABLES AND PARAMETERS

ADD	=	Average daily dose (mg COPC/kg BW-day)
ADD_{infant}	=	Average daily dose for infant exposed to contaminated breast milk (pg [or mg] COPC/kg BW infant/day)
ADD_{mat}	=	Average daily dose, mother (pg COPC/kg BW mother/day)
ADI	=	Average daily COPC intake via inhalation (mg COPC/kg BW-day)
$AHQ_{inh(I)}$	=	Acute hazard quotient for inhalation of COPCs (unitless)
$AIEC$	=	COPC acute inhalation exposure criteria (mg/m ³)
A_i	=	Concentration of COPC I in animal tissue j (mg COPC/kg FW tissue)
AT	=	Averaging time (yr)
AT_{infant}	=	Averaging time for infant (yr)
BW	=	Body weight (kg)
BW_{infant}	=	Body weight of infant (kg)
C_a	=	Total COPC air concentration (:g/m ³)
C_{acute}	=	Acute air concentration (:g/m ³)
$Cancer\ Risk_i$	=	Individual lifetime risk through indirect exposure to COPC carcinogen I (unitless)
$Cancer\ Risk_{inh(I)}$	=	Individual lifetime cancer risk through direct inhalation of COPC carcinogen I (unitless)
C_{dw}	=	Dissolved phase water concentration (mg COPC/L water)
C_{fish}	=	Concentration in fish (mg COPC/kg FW tissue)
$C_{milk\ fat}$	=	Concentration in milk fat of breast milk for a specific exposure scenario (pg [or mg] COPC/kg milk fat)
CR_{ag}	=	Consumption rate of aboveground produce (kg DW plant/kg BW-day)
CR_{bg}	=	Consumption rate of belowground produce (kg DW plant/kg BW-day)
CR_{dw}	=	Consumption rate of drinking water (L water/day)
CR_{fish}	=	Consumption rate of fish (kg/kg BW-day)
CR_j	=	Consumption rate of animal tissue j (kg/kg-day FW)
CR_{pp}	=	Consumption rate of protected aboveground produce (kg DW plant/kg BW-day)
CR_{soil}	=	Consumption rate of soil (kg soil/day)
C_s	=	Average soil concentration over exposure duration (mg COPC/kg soil)
ED	=	Exposure duration (yr)
ED_{infant}	=	Exposure duration of infant to breast milk (yr)
EF	=	Exposure frequency (days/yr)
ET	=	Exposure time (hrs/day)
f_1	=	Fraction of ingested dioxin that is stored in fat (unitless)
f_2	=	Fraction of mother's weight that is fat (unitless)
f_3	=	Fraction of mother's breast milk that is fat (unitless)
f_4	=	Fraction of ingested COPC that is absorbed (unitless)
F_{ag}	=	Fraction of produce that is contaminated (unitless)
F_{bg}	=	Fraction of belowground produce that is contaminated (unitless)
F_{dw}	=	Fraction of drinking water that is contaminated (unitless)
F_{fish}	=	Fraction of fish that is contaminated (unitless)
F_j	=	Fraction of animal tissue j that is contaminated (unitless)
F_{soil}	=	Fraction of soil that is contaminated (unitless)

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LIST OF VARIABLES AND PARAMETERS (Continued)

h	=	Half-life of dioxin in adults (days)
$HI_{inh(j)}$	=	Hazard index for target organ effect j through direct inhalation of all COPCs (unitless)
HI_j	=	Hazard index for exposure pathway j (unitless)
HQ_i	=	Hazard quotient for COPC I (unitless)
$HQ_{inh(I)}$	=	Hazard quotient for direct inhalation of COPC I (unitless)
I	=	Total daily intake of COPC (mg COPC/kg BW-day)
I_i	=	Daily intake of COPC I from animal tissue j (mg COPC/kg BW-day)
I_{ag}	=	Daily intake of COPC from produce (mg COPC/kg BW-day)
I_{bg}	=	Daily intake of COPC from belowground produce (mg COPC/kg BW-day)
I_{dw}	=	Daily intake of COPC from drinking water (mg COPC/kg BW-day)
I_{fish}	=	Daily intake of COPC from fish (mg COPC/kg BW-day)
I_{soil}	=	Daily intake of COPC from soil (mg COPC/kg BW-day)
$Inhalation\ CSF$	=	Inhalation cancer slope factor (mg/kg-day) ⁻¹
IR	=	Inhalation rate (m ³ /hr)
IR_{milk}	=	Ingestion rate of breast milk by the infant (kg/day)
$LADD$	=	Lifetime average daily dose (mg COPC/kg BW-day)
m	=	Average maternal intake of dioxin for each adult exposure scenario (mg COPC/kg BW-day)
$Oral\ CSF$	=	Oral cancer slope factor (mg/kg-day) ⁻¹
P_d	=	Aboveground exposed produce concentration due to direct (wet and dry) deposition onto plant surfaces (mg COPC/kg DW)
P_i	=	Total COPC concentration in plant type I eaten by the animal (mg/kg DW)
P_r	=	Aboveground exposed and protected produce concentration due to root uptake (mg COPC/kg DW)
$P_{r_{bg}}$	=	Belowground produce concentration due to root uptake (mg COPC/kg DW)
P_v	=	Concentration of COPC in plant due to air-to-plant transfer (mg COPC/kg DW)
RfC	=	Reference concentration (mg/kg)
RfD	=	Reference dose (mg/kg-day)
$Total\ Cancer\ Risk$	=	Individual lifetime cancer risk through indirect exposure to all COPC carcinogens (unitless)
$Total\ Cancer\ Risk_{inh}$	=	Total individual lifetime cancer risk through direct inhalation of all COPC carcinogens (unitless)
URF	=	Unit risk factor (μg/m ³) ⁻¹

EQUATION F-1-1

COPC INTAKE FROM SOIL

$$I_{soil} = \frac{Cs \bullet CR_{soil} \bullet F_{soil}}{BW}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
I_{soil}	Daily intake of COPC from soil	(mg/kg-day)
Cs	Average soil concentration over exposure duration	Calculated using Equation F-1-1 (mg/kg)
CR_{soil}	Consumption rate of soil	Adult = 0.00005 kg/day; Child = 0.0001 kg/day
F_{soil}	Fraction of soil that is contaminated	1.0 (unitless)
BW	Body weight	Adult = 70 kg; Child = 15 kg

EQUATION F-1-2

COPC INTAKE FROM PRODUCE

$$I_{ag} = \left[\left((Pd + Pv + Pr) \bullet CR_{ag} \right) + \left(Pr + CR_{pp} \right) + \left(Pr_{bg} + CR_{bg} \right) \right] \bullet F$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
I_{ag}	Daily intake of COPC from produce	(mg/kg-day DW)
Pd	Aboveground exposed produce concentration due to direct (wet and dry) deposition onto plant surfaces	Calculated using Equation F-2-7 (mg/kg).
Pv	Aboveground exposed produce concentration due to air-to-plant transfer	Calculated using Equation F-2-8 (mg/kg)
Pr	Aboveground exposed and protected produce concentration due to root uptake	Calculated using Equation F-2-9 (mg/kg)
Pr_{bg}	Belowground produce concentration due to root uptake	Calculated using Equation F-2-10 (mg/kg)
CR_{ag}	Consumption rate of aboveground produce	Adult = 0.0003 kg/kg-day DW Child = 0.00042 kg/kg-day DW
CR_{pp}	Consumption rate of protected aboveground produce	Adult = 0.00057 kg/kg-day DW Child = 0.00077 kg/kg-day DW
CR_{bg}	Consumption rate of belowground produce	Adult = 0.00014 kg/kg-day DW Child = 0.00022 kg/kg-day DW
F_{ag}	Fraction of produce that is contaminated	Adult and child resident = 0.25 (unitless) Subsistence farmer and child = 1.0 (unitless) Subsistence fisher and child = 0.25 (unitless)

EQUATION F-1-3
COPC INTAKE FROM BEEF, MILK, PORK, AND EGGS

$$I_i = A_i \bullet CR_i \bullet F_i$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
I_i	Daily intake of COPC i from animal j tissue	(mg/kg-day)
A_i	Concentration of COPC i in animal tissue j	Calculated using Equations D-3-10 through D-3-14 (mg/kg FW)
CR_j	Consumption of animal tissue j	<u>Homegrown beef</u> Adult = 0.00114 kg/kg-day FW Child = 0.00051 kg/kg-day FW <u>Homegrown milk</u> Adult = 0.00842 kg/kg-day FW Child = 0.01857 kg/kg-day FW <u>Homegrown poultry</u> Adult = 0.00061 kg/kg-day FW Child = 0.000425 kg/kg-day FW <u>Homegrown eggs</u> Adult = 0.00062 kg/kg-day FW Child = 0.000438 kg/kg-day FW <u>Homegrown pork</u> Adult = 0.00053 kg/kg-day FW Child = 0.000398 kg/kg-day FW
F_j	Fraction of animal tissue j that is contaminated	1.0 (unitless)

EQUATION F-1-4
COPC INTAKE FROM FISH

$$I_{fish} = C_{fish} \bullet CR_{fish} \bullet F_{fish}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
I_{fish}	Daily intake from fish	(mg/kg-day)
C_{fish}	Concentration in fish	Calculated using Equation F-4-28 (mg/kg)
CR_{fish}	Consumption rate of fish	Adult = 0.00117 kg/kg-day FW; Child = 0.000759 kg/kg-day FW
F_{fish}	Fraction of fish that is contaminated	1.0 (unitless)

EQUATION F-1-5
COPC INTAKE FROM DRINKING WATER

$$I_{dw} = \frac{C_{dw} \bullet CR_{dw} \bullet F_{dw}}{BW}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
I_{dw}	Daily intake of COPC from drinking water	(mg/kg-day)
C_{dw}	Dissolved phase water concentration	Calculated using Equation F-4-24 (mg/L)
CR_{dw}	Rate of consumption of drinking water	Adult = 1.4 L/day; Child = 0.67 L/day
F_{dw}	Fraction of drinking water that is contaminated	1.0 (unitless)
BW	Body weight	Adult = 70 kg; Child = 15 kg

EQUATION F-1-6

TOTAL DAILY INTAKE

$$I = I_{soil} + I_{ag} + I_{beef} + I_{milk} + I_{fish} + I_{pork} + I_{eggs} + I_{dw}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
I	Total daily intake of COPC	(mg/kg-day)
I_{soil}	Total daily intake of COPC from soil	Calculated using Equation F-1-1 (mg/kg-day)
I_{ag}	Total daily intake of COPC from aboveground produce	Calculated using Equation F-1-2 (mg/kg-day DW)
I_{beef}	Total daily intake of COPC from beef	Calculated using Equation F-1-3 (mg/kg-day FW)
I_{milk}	Total daily intake of COPC from milk	Calculated using Equation F-1-4 (mg/kg-day FW)
I_{fish}	Total daily intake of COPC from fish	Calculated using Equation F-1-5 (mg/kg-day FW)
I_{pork}	Total daily intake of COPC from pork	Calculated using Equation F-1-6 (mg/kg-day FW)
I_{eggs}	Total daily intake of COPC from eggs	Calculated using Equation F-1-7 (mg/kg-day FW)
I_{dw}	Total daily intake of COPC from drinking water	Calculated using Equation F-1-8 (mg/kg-day)

EQUATION F-1-7

INDIVIDUAL CANCER RISK: CARCINOGENS

$$CancerRisk_i = \frac{I_i \bullet ED \bullet EF \bullet Oral\ CSF}{AT \bullet 365}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
<i>Cancer Risk_i</i>	Individual lifetime cancer risk through indirect exposure to COPC carcinogen <i>i</i>	(unitless)
<i>I_i</i>	Daily intake of COPC <i>i</i> from animal tissue <i>j</i>	Calculated using Equation F-1-6 (mg COPC/kg BW-day)
<i>ED</i>	Exposure duration	Child resident, Subsistence Farmer child, and Subsistence Fisher child = 6 yr Adult resident and Subsistence Fisher = 30 yr Subsistence Farmer = 40 yr
<i>EF</i>	Exposure frequency	350 days/year
<i>AT</i>	Averaging time	70 yr
<i>365</i>	Units conversion factor	365 days/yr
<i>Oral CSF</i>	Oral cancer slope factor	See Appendix C (mg/kg-day) ⁻¹

EQUATION F-1-8

HAZARD QUOTIENT: CARCINOGENS

$$HQ = \frac{I_i \bullet ED \bullet EF}{RfD \bullet AT \bullet 365}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
<i>HQ</i>	Hazard quotient	(unitless)
<i>I_i</i>	Daily intake of COPC <i>i</i> from animal tissue <i>j</i>	Calculated using Equation F-1-6 (mg COPC/kg-day)
<i>ED</i>	Exposure duration	Child resident, Subsistence farmer child, and Subsistence fisher child = 6 yr Adult resident and Subsistence fisher = 30 yr Subsistence farmer = 40 yr
<i>EF</i>	Exposure frequency	350 days/yr
<i>RfD</i>	Reference dose	See Appendix C (mg/kg-day)
365	Units conversion factor	365 days/yr
<i>AT</i>	Averaging time	6, 30, or 40 yrs; the AT for noncarcinogens is equal to the ED

EQUATION F-1-9
TOTAL CANCER RISK: CARCINOGENS

$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
<i>Total Cancer Risk</i>	Individual lifetime cancer risk through indirect exposure to all COPC carcinogens	(unitless)
<i>Cancer Risk_i</i>	Individual lifetime cancer risk through indirect exposure to COPC carcinogen <i>i</i>	Calculated using Equation F-1-7 (unitless)

EQUATION F-1-10

TOTAL HAZARD INDEX: NONCARCINOGENS

$$\text{Total Hazard Index} = \sum_j HI_j$$

$$HI_j = \sum_i HQ_i$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
<i>Total Hazard Index</i>	Total individual hazard index for all COPCs across all exposure pathways	(unitless)
<i>HI_j</i>	Hazard index for exposure pathway <i>j</i>	(unitless)
<i>HQ_i</i>	Hazard quotient for COPC <i>i</i>	(unitless)

EQUATION F-1-11

SEGREGATED HAZARD INDEX FOR SPECIFIC ORGAN EFFECTS

$$HI_j = \sum_i HQ_i$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
HI_j	Hazard index for exposure pathway j	(unitless)
HQ_i	Hazard quotient for COPC i	Calculated using Equation F-1-8 (unitless)

EQUATION F-2-1

INHALATION CANCER RISK FOR INDIVIDUAL CHEMICALS: CARCINOGENS

$$Cancer\ Risk_{inh(i)} = ADI \bullet CSF_{inh(i)}$$

$$ADI = \frac{C_a \bullet IR \bullet ET \bullet EF \bullet ED \bullet 0.001\ mg / \mu g}{BW \bullet AT \bullet 365\ days / yr}$$

$$CSF_{inh(i)} = \frac{URF \bullet 70 \bullet 10^3\ \mu g / mg}{20\ m^3 / day}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
$Cancer\ Risk_{inh(i)}$	Individual lifetime cancer risk through direct inhalation of COPC carcinogen I	(unitless)
ADI	Average daily COPC intake via inhalation	See Table C-1 (mg COPC/kg-day)
$Inhalation\ CSF$	Inhalation cancer slope factor	See Table C-1 (mg/kg-day) ⁻¹
URF	Inhalation unit risk factor	See Table C-1 (μg/m ³) ⁻¹
C_a	Total COPC air concentration	Calculated in Equation F-5-1 (μg/m ³)
IR	Inhalation rate	Adult = 0.63 m ³ /hr; child = 0.30 m ³ /hr
ET	Exposure time	24 hrs/day
EF	Exposure frequency	350 days/yr

EQUATION F-2-1 (Continued)

INHALATION CANCER RISK FOR INDIVIDUAL CHEMICALS: CARCINOGENS

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
<i>ED</i>	Exposure duration	Subsistence farmer = 40 yr Subsistence farmer child = 6 yr Subsistence fisher = 30 yr Subsistence fisher child = 6 yr Adult resident = 30 yr Child resident = 6 yr
<i>BW</i>	Body weight	Adults = 70 kg; child = 15 kg
<i>AT</i>	Averaging time	70 yr

EQUATION F-2-2

INHALATION HAZARD QUOTIENT FOR COPCS: NONCARCINOGENS

$$HQ_{inh(i)} = \frac{ADI}{RfD}$$

$$ADI = \frac{C_a \bullet IR \bullet ET \bullet EF \bullet ED \bullet 0.001 \text{ mg} / \mu\text{g}}{BW \bullet AT \bullet 365 \text{ days} / \text{yr}}$$

$$RfD = \frac{RfC \bullet 20 \text{ m}^3 / \text{day}}{70 \text{ kg}}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
$HQ_{inh(i)}$	Hazard quotient for direct inhalation of COPC noncarcinogen i	(unitless)
ADI	Average daily COPC intake via inhalation	(mg COPC/kg-day)
C_a	Total air COPC concentration	Calculated using Equation F-5-1 ($\mu\text{g}/\text{m}^3$)
RfD	Reference dose	See Table C-1 (mg/kg-day)
RfC	Reference concentration	See Table C-1 (mg/m^3)
IR	Inhalation rate	Adults = $0.63 \text{ m}^3/\text{hr}$; child = $0.30 \text{ m}^3/\text{hr}$
ET	Exposure time	24 hrs/day
EF	Exposure frequency	350 days/yr

EQUATION F-2-2 (Continued)

INHALATION HAZARD QUOTIENT FOR COPCS: NONCARCINOGENS

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
<i>ED</i>	Exposure duration	Subsistence farmer = 40 yr Subsistence farmer child = 6 yr Subsistence fisher = 30 yr Subsistence fisher child = 6 yr Adult resident = 30 yr Child resident = 6 yr
<i>BW</i>	Body weight	Adult = 70 kg; child = 15 kg
<i>AT</i>	Averaging time	6, 30, or 40 yrs; the AT for noncarcinogens is equal to the ED

EQUATION F-2-3

TOTAL INHALATION CANCER RISK: CARCINOGENS

$$Total\ Cancer\ Risk_{inh} = \sum_i Cancer\ Risk_{inh(i)}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
$Total\ Cancer\ Risk_{inh}$	Total individual lifetime cancer risk through direct inhalation of all COPC carcinogens	(unitless)
$Cancer\ Risk_{inh(i)}$	Individual lifetime cancer risk through direct inhalation for COPC carcinogen i	Calculated using Equation F-2-1 (unitless)

EQUATION F-2-4

HAZARD INDEX FOR INHALATION: CARCINOGENS

$$HI_{inh} = \sum_i HQ_i$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
$HI_{inh(i)}$	Hazard index for target organ effect j through direct inhalation of all COPCs	(unitless)
$HQ_{inh(i)}$	Hazard quotient for direct inhalation of COPC i	Calculated using Equation F-2-3 (unitless)

EQUATION F-3-1

CONCENTRATION OF DIOXINS IN BREAST MILK

$$C_{milkfat} = \frac{m \bullet 1 \times 10^9 \bullet h \bullet f_1}{0.693 \bullet f_2}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
$C_{milkfat}$	Concentration of dioxin in milk fat of breast milk for a specific exposure scenario	(pg COPC/kg milk fat)
m	Average maternal intake of dioxin for each exposure scenario	Calculated using Equation F-1-6 (mg COPC/kg BW-day)
1×10^9	Units conversion factor	1×10^9 pg/mg
h	Half-life of dioxins in adults	2,555 (days)
f_1	Fraction of ingested dioxin that is stored in fat	0.9 (unitless)
f_2	Fraction of mothers weight that is fat	0.3 (unitless)

EQUATION F-3-2

AVERAGE DAILY DOSE TO THE EXPOSED INFANT

$$ADD_{inf\ ant} = \frac{C_{milkfat} \bullet f_3 \bullet f_4 \bullet IR_{milk} \bullet ED}{BW_{inf\ ant} \bullet AT}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
ADD_{infant}	Average daily dose for infant exposed to contaminated breast milk	(pg COPC/kg BW-day)
$C_{milkfat}$	Concentration of COPC in milk fat of breast milk for a specific exposure scenario	Calculated using Equation F-3-1 (pg COPC/kg milk fat)
f_1	Fraction of mother's breast milk that is fat	0.04 (unitless)
f_4	Fraction of ingested COPC that is absorbed	0.9 (unitless)
IR_{milk}	Ingestion rate of breast milk by the infant	0.8 kg/day
ED	Exposure duration	1 yr
BW_{infant}	Body weight of infant	10 kg
AT	Averaging time	1 yr

EQUATION F-4-1
ACUTE HAZARD QUOTIENT

$$AHQ_{inh(i)} = \frac{C_{acute} \bullet 0.001}{AIEC}$$

<u>Variable</u>	<u>Description</u>	<u>Value and Units</u>
$AHQ_{inh(i)}$	Acute hazard quotient for inhalation of COPCs	(unitless)
C_{acute}	Acute air concentration	Calculated using Equation F-6-1 ($\mu\text{g}/\text{m}^3$)
$AIEC$	COPC acute inhalation exposure criteria	COPC-specific (mg/m^3)
0.001	Conversion factor	0.001 $\text{mg}/\mu\text{g}$
